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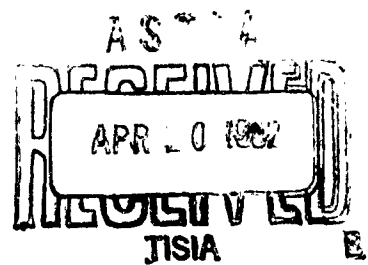
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**U. S. NAVAL AVIONICS FACILITY**  
INDIANAPOLIS, INDIANA

**TECHNICAL REPORT**



U. S. NAVAL AVIONICS FACILITY  
Indianapolis, Indiana

TECHNICAL REPORT

RESEARCH, ENGINEERING & TECHNICAL EVALUATION  
DEPARTMENTS

Report Number TR-92

16 October 1961

PRINTED WIRING BOARDS, DIELECTRIC  
STRENGTH OF

(DOD Project No. X999-0028)

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NOTICE

Technical Report No. TR-92 was formerly assigned the number "Materials Report No. 59". The former number may have been referenced on other documents. However, by the time this report was actually issued, the numbering system had been changed, and the report was issued as Technical Report No. TR-92.

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PREFACE

The purpose of this report is to present corona and breakdown voltage information, for use in the design of printed wiring boards for high altitude applications. These data were intended as background information for the conductor spacing recommendations in MIL-STD-275A.

The complete mass of raw data is published in this report, in addition to the recommended conductor spacings, because of repetitive requests by design engineers who prefer to review the raw data and set their own safety factors for each particular design application. For all others, the MIL-STD-275 conductor spacing tables, which include generous safety factors, are recommended.

ABSTRACT

This report establishes recommended spacings between the conductors on printed wiring boards. The corona discharge and dielectric breakdown voltages were measured for each of ten different spacings: .010, .015, .022, .025, .032, .062, .093, .125, .187, and .250 inches. The conditions of the test were based on parameters from MIL-STD-446 and MIL-E-5400. The tests are summarized as follows:

ALTITUDE FEET	RELATIVE HUMIDITY	TEMPERATURE °C (°F)	SPECIMEN MATERIALS	REF. MTR NO.
Sea level	Room humidity	Room temperature	epoxy	14-57
Sea level	90%	21°C (70°F)	epoxy	81-59
10,000	91%	125°C (257°F)	epoxy & phenolic	-
50,000	90%	Room temperature	epoxy	14-57
50,000	90%	21°C (70°F)	epoxy	81-59
50,000	91%	125°C (257°F)	epoxy & phenolic	-
50,000	100% with condensation	55°C (131°F)	epoxy & phenolic	50-60
70,000	90%	21°C (70°F)	epoxy	81-59
70,000	100% with condensation	71°C (160°F)	epoxy & phenolic	50-60
80,000	room humidity	150°C (302°F)	epoxy	93-61
80,000	90%	21°C (70°F)	epoxy	81-59
80,000	91%	125°C (257°F)	epoxy & phenolic	50-60
80,000	100% with condensation	95°C (203°F)	epoxy & phenolic	50-60
100,000	91%	125°C (257°F)	epoxy & phenolic	50-60

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## I. CONCLUSIONS

Corona information can be obtained accurately and reproducibly, by the procedures outlined in this report. However, the MIL-STD-446 design parameters specify nonequilibrium conditions, such as high altitude plus high temperature plus high humidity, because these seemingly impossible conditions are present in airborne military electronic equipment. Therefore, it is concluded that corona tests are valid, only if all of the required conditions are met; extrapolation is of doubtful value.

The raw data in this report represent the conditions where failure is sure to occur. Because printed wiring boards should be designed so as not to fail, it is concluded that adequate safety factors should be used.

The test specimens were burnished with fine steel wool prior to corona testing to remove all points and sharp edges which could serve as focal points for corona. However, actual printed wiring boards will not be burnished, and several points and sharp edges may be present. No two printed wiring boards will be alike, in this respect, therefore it is concluded that the safety factor should be sufficiently large to cover this feature.

## II. RECOMMENDATIONS

The recommended conductor spacings are listed below. These values, which include safety factors, were published in MIL-STD-275A.

The minimum recommended spacing between conductors, for power up to and including 50 watts, should be as indicated in the table below. For applications where secondary circuit protection is provided in the form of fuses, circuit breakers, etc., and where the normal operating power is greater than 50 watts but does not exceed 2000 watts, the minimum spacing between conductors shall be twice that indicated in the tables below.

Recommended conductor spacing for uncoated boards from sea level to 10,000 feet inclusive:

Voltage between conductors (DC or AC peak volts)	Minimum Spacing	
	inches	
	Grade A	Grade B
0 to 50	.015	.080
51 to 150	.026	.080
151 to 300	.062	.125
301 to 500	.125	.300



## NAFI REPORT TR-92

The recommended minimum spacing between conductors on uncoated boards should be in accordance with the table below when the boards are subjected to reduced pressure equivalent to altitudes greater than 10,000 feet with powers up to and including 50 watts for normal service environments. Where the board will be directly exposed to severe contamination, additional spacing shall be provided based on the particular application or coated boards shall be used.

Recommended conductor spacings, for uncoated boards, for use above 10,000 feet:

Voltage between conductors (DC or AC peak volts)	Minimum Spacing  inches
0 to 50	.026
51 to 100	.062
101 to 170	.125
171 to 250	.250
251 to 500	.500

### III. BACKGROUND INFORMATION

The measurement of corona discharge voltages, for various conductor spacings, at various altitudes and at various humidities, was performed by the U. S. Naval Avionics Facility, Indianapolis, for the purpose of obtaining data for publication in MIL-STD-275A.

The design parameters, such as altitude, temperature, and relative humidity were selected from MIL-STD-446 and MIL-E-5400. Ten different conductor spacings were selected.

### IV. DESCRIPTION AND DISCUSSION

#### A. PROCEDURES

##### 1. Introduction

Inasmuch as this report is a compilation of several separate tests, which were performed at different times with different apparatus, each procedure will be discussed separately. In general, however, each test involved three common features:

a. Placing the specimens in the desired atmosphere of vacuum, temperature, and relative humidity.

b. Connecting the specimens to a power supply, meters, and

gradually increasing the potential until corona occurred. Corona was detected on an oscilloscope. See Figure 1.

c. Measuring the corona discharge voltage at the instant it occurs.

## 2. Specimen Preparation

All of the larger specimens were prepared by screen process printing. The two smaller specimens, AV 1703 and AV 1704, were prepared photographically, using Kodak Photo Resist. The specimens were etched in ammonium persulfate solution and were visually inspected using 24 X magnification. Before the corona test, the specimens were rubbed vigorously with fine steel wool in the lengthwise direction and degreased with clean liquid trichloroethylene. The steel wool removed tiny points and sharp edges which could serve as focal points for corona.

## 3. Procedure for 90% RH

The procedure is as follows:

a. A glass desiccator jar was used to hold three test specimens under conditions of 90% relative humidity at 21°C (70°F) and at the various altitude pressures. A saturated solution of potassium nitrate in the bottom of the jar was used to obtain the humidity. The air pressure used for simulating the various altitudes was obtained from the Tenny Altitude Conversion Table.

b. Electrical connections were made inside the jar by potting wires through the desiccator lid. Also potted into the lid was a glass tube branching to a vacuum pump and a dial type vacuum gage. The relative humidity was measured with an Aminco Electric Hydrometer.

c. Three specimens of the same part number and the hydrometer sensing element were soldered to the wires in the desiccator lid. The jar was evacuated to the desired pressure. The humidity was checked periodically until 90% RH was reached and testing was started.

d. The corona and breakdown voltages were determined by using a Hi-Pot (High Voltage Tester, Industrial Instruments, Inc.) equipped with an auxiliary AC voltmeter having a range of 1,000 volts. An oscilloscope was used to determine when corona started. The electrical circuit is shown in Figure 1. Each specimen was tested individually, first for corona, and then breakdown. Voltage was slowly increased until a blue glow (corona) was observed between the copper lines, or the waveform on the oscilloscope became distorted. The oscilloscope was then disconnected and the voltage was increased until breakdown, indicated by the circuit breaker.

## 4. Procedure for 100% RH

a. The apparatus listed and shown in several prints was set up to determine the dielectric strength of various printed circuit boards.

b. The prints show how the apparatus was used and how the boards were placed in the stainless steel bell jar. One container, a large Pyrex dish, was placed below the specimens; the other, a stainless steel container, was placed above the specimens. It rested on a shield that contained the heaters. Water was placed in both to obtain the humidity.

c. The stainless steel bell jar was sealed and heated until the desired temperature and humidity was reached. Then the system was opened to the pumps and the desired altitude was simulated. The tests were completed with the results shown in the tables.

## B. SPECIMENS

### 1. Sizes

The following table lists the specimens by number, conductor spacing, and conductor width.

PART NO.	CONDUCTOR SPACING	CONDUCTOR WIDTH
AV 1703	.010	.010
AV 1704	.015	.015
AV 1705	.022	.022
AV 1706	.025	.025
AV 1707	.032	.032
AV 408	.062	.062
AV 409	.093	.093
AV 410	.125	.125
AV 411	.187	.187
AV 412	.250	.250

### 2. Materials

Printed wiring boards are ordinarily made of either paper phenolic laminate or glass epoxy laminate. Specimens for these tests were made from each material. None of the specimens was coated with varnish prior to testing.

a. Phenolic. MIL-P-13949B, FL-PP-062-C-2/0

b. Epoxy. MIL-P-13949B, FL-GE-062-C-2/0

## C. APPARATUS

### 1. A Screen Process Printing Press (BuWeps Dwg. No. DS 643)

The ink resist was Naz-Dar No. 211.

### 2. Photographic Equipment for the Kodak Photo Resist Process

This included a lamp for exposure, a rotary turntable for drying the KPR, and a small trichloroethylene vapor degreaser for developing the KPR.

### 3. Etching Equipment

A bubble etcher was used (AV 1633) with an etching solution consisting of:

ammonium persulfate 298 gm/l (2.5 lb/gal)

66° Be sulfuric acid 15.5 ml/l (59 ml/gal)

The temperature was 43°C (110°F).

The air pressure was 10 psig, and bubble agitation was uniformly distributed.

### 4. Microscope

Spencer Serial No. 199211, 24 X, binocular

5. An 18" stainless steel bell jar, pumps, etc., approximately (13 cubic feet per min.)

6. Ti-Pot (Industrial Instruments, Inc.)

7. Variac - 10 amps (Superior Electric Co.)

8. Specimen holder, AV 2806

9. Infrared Heater. (special)

10. Two containers for Water

11. Potentiometer (L & N #1160124)

12. Barometer, mercurial, range 1,000 to 200,000 feet (Hass Bro. Instrument Co., U.S.N. BuOrd 015405)

13. Oscilloscope

14. Hydrometer (Aminco)

### D. EXPLANATION OF 100% RH

MIL-STD-446 requires 100% relative humidity with condensation. In this test it was possible to get a momentary 100% RH with profuse condensation, but equilibrium was reached faster than the hydrometer could function; so the actual measured values never exceeded 91% RH. The data is reported as "100% RH with condensation" because 100% RH was the actual condition at the moment of corona.

MIL-STD-446 requires 100% RH with condensation at 125°C at all altitudes. Condensation is nearly impossible at 80,000 feet altitude, and is completely impossible at altitudes higher than 80,000 feet. Therefore, the data in this report are recommended for all designs which must comply with MIL-STD-446 at all altitudes up to and including 100,000 feet.

APPENDIX

A. TABLES

1. Corona discharge voltages for various altitudes.

B. FIGURES

1. Schematic - Sketch
2. Rack Assembly
3. Specimens
4. Specimens
5. Specimens

C. PHOTOGRAPHS

1. Test chamber after testing has been completed. (Notice the condensed moisture.)
2. Test chamber while operating.
3. Power supply and associated electrical measuring instruments.

Conductor Spacing	SEA LEVEL 90% RH 21°C (70°F) EPOXY SPECIMENS (See MTR 81-59)		SEA LEVEL ROOM CONDITIONS EPOXY SPECIMENS (See MTR 14-57)	
	CORONA DISCHARGE	BREAKDOWN	HI-POT SETTING AT BREAKDOWN 60 cycle AC	BREAKDOWN 60 cycle AC
inches	volts	volts	volts rms	volts rms
.010	none	550	1400	1000
	none	500		1400
	none	700		
	none	670		
		Avg 605		Avg 1200
.015	none	870	1400	1200
	none	800		1200
	none	900		
		Avg 857		Avg 1200
.022	none	1300	1500	1300
	none	1200		1400
	none	1100		
		Avg 1200		Avg 1350
.025	none	1300	1100	1600
	none	1200		1400
	none	1200		
		Avg 1233		Avg 1500
.032	none	1280	1425	1500
	none	1400		1700
	none	1300		
		Avg 1327		Avg 1600

Conductor Spacing	10,000 FEET 91% RH 125°C (257°F) EPOXY SPECIMENS		10,000 FEET 91% RH 125°C (257°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
inches	volts	volts	volts	volts
.010	400	400	440	440
	- -	- -	490	490
	- -	- -	580	580
	520	520	520	520
	580	580	560	650
	540	540	630	630
	Avg 510	Avg 510	Avg 537	Avg 552
.015	720	720	740	740
	- -	- -	700	750
	660	660	670	670
	- -	- -	630	680
	640	640	740	740
	750	750	- -	750
	Avg 692	Avg 692	Avg 696	Avg 722
.022	920	920	600	600
	1160	1160	1000	1000
	1000	1000	800	800
	930	930	950	950
	840	840	850	850
	740	740	800	800
	Avg 932	Avg 932	Avg 833	Avg 833
.025	1140	1140	1000	1000
	1230	1230	1050	1050
	1100	1100	1100	1100
	800	800	1040	1040
	1100	1100	1000	1000
	1100	1100	1050	1050
	Avg 1078	Avg 1078	Avg 1040	Avg 1040
.032	1360	1360	1040	1040
	1100	1310	1160	1160
	1300	1300	1200	1200
	1150	1150	1050	1120
	1360	1360	1050	1050
	1150	1150	1060	1060
	Avg 1237	Avg 1272	Avg 1093	Avg 1105

Conductor Spacing	10,000 FEET 91% RH 125°C (257°F) EPOXY SPECIMENS		10,000 FEET 91% RH 125°C (257°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
inches	volts	volts	volts	volts
.062	1460	1560	1500	1500
	1000	1000	1550	1740
	1400	1500	1600	1700
	1400	1400	1500	1580
	1300	1350	1730	1730
	1350	1400	1600	1600
	Avg 1318	Avg 1368	Avg 1580	Avg 1642
.093	1800	1800	1660	1950
	1810	1850	1950	2050
	- -	- -	2030	2030
	1750	1800	2040	2040
	1720	1720	2140	2140
	- -	- -	2000	2000
	Avg 1770	Avg 1792	Avg 1970	Avg 2035
.125	1350	1350	2000	2400
	2070	2070	2100	2100
	1650	1700	1800	2200
	1470	1470	2030	2030
	1250	1250	2100	2100
	1400	1400	1740	1740
	Avg 1532	Avg 1540	Avg 1962	Avg 2095
.187	650	650	- -	3000
	1300	1300	3000	3000
	- -	- -	2200	2200
	- -	- -	2400	2400
	950	1050	2100	2100
	- -	- -	1900	1900
	Avg 967	Avg 1000	Avg 2320	Avg 2433
.250	1900	1900	- -	2300
	2140	2140	3500	3500
	1900	2300	2100	2500
	2200	2200	2700	2700
	1750	1750	2400	2400
	2200	2200	2510	2510
	Avg 2015	Avg 2082	Avg 2642	Avg 2652



Conductor Spacing	50,000 FEET 90% RH ROOM TEMPERATURE EPOXY SPECIMENS (from MTR 14-57)		50,000 FEET 90% RH 21°C (70°F) EPOXY SPECIMENS (from MTR 81-59)	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
inches	volts	volts	volts	volts
.010	320	330	310	400
	330		320	410
	340		320	420
	320			
	330			
	330			
	Avg 328	Avg 330	Avg 317	Avg 410
.015	370	450	360	430
	390		360	440
	420		350	430
	400			
	385			
	380			
	Avg 390	Avg 442	Avg 357	Avg 433
.022	390	480	370	450
	440		350	460
	490		370	460
	490			
	430			
	490			
	Avg 455	Avg 480	Avg 363	Avg 457
.025	480	480	390	450
	500		370	450
	490		370	450
	480			
	500			
	Avg 490	Avg 480	Avg 377	Avg 450
.032	540	500	400	410
	510		380	450
	510		400	440
	490			
	520			
	490			
	Avg 510	Avg 500	Avg 393	Avg 433

Conductor Spacing	50,000 FEET 91% RH 125°C (257°F) EPOXY SPECIMENS		50,000 FEET 91% RH 125°C (257°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
	volts	volts	volts	volts
inches				
.010	290	---	350	520
	---	---	350	450
	340	460	300	480
	340	440	340	490
	350	480	340	430
	330	440	350	470
	Avg 330	Avg 455	Avg 338	Avg 473
.015	350	490	360	460
	330	510	360	470
	400	470	340	470
	400	460	350	520
	400	480	310	500
	390	460	340	480
	Avg 378	Avg 478	Avg 343	Avg 483
.022	380	530	---	---
	500	800	400	560
	510	800	450	550
	480	500	450	570
	450	500	450	580
	470	740	480	520
	Avg 465	Avg 645	Avg 446	Avg 556
.025	420	540	530	550
	500	760	450	500
	510	840	400	550
	490	690	490	570
	470	630	480	590
	470	600	470	590
	Avg 477	Avg 677	Avg 470	Avg 558
.032	450	510	500	580
	550	820	460	530
	400	560	420	570
	520	580	470	580
	---	---	480	590
	520	740	470	570
	Avg 488	Avg 642	Avg 467	Avg 570

Conductor Spacing	50,000 FEET 91% RH 125°C (257°F) EPOXY SPECIMENS		50,000 FEET 91% RH 125°C (257°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
	volts	volts	volts	volts
inches				
.062	600	720	730	730
	560	690	690	690
	650	670	610	660
	640	720	640	640
	740	770	640	660
	610	770	650	650
	Avg 633	Avg 723	Avg 660	Avg 672
.093	700	870	930	930
	850	850	880	900
	810	860	730	780
	750	820	730	800
	950	950	770	770
	630	860	800	800
	Avg 782	Avg 868	Avg 807	Avg 830
.125	1090	1140	1020	1160
	830	1060	1100	1140
	820	1050	1000	1050
	---	950	1030	1030
	---	1110	950	1050
	850	960	1000	1050
	Avg 897	Avg 1045	Avg 1017	Avg 1080
.187	1100	1200	1250	1540
	900	1090	1240	1280
	---	950	1140	1260
	---	1070	1150	1250
	950	1050	1240	1240
	650	650	1190	1190
	Avg 900	Avg 1002	Avg 1202	Avg 1293
.250	1200	1360	1600	1600
	900	1190	1400	1450
	750	1050	1350	1450
	---	1200	1400	1450
	1000	1100	1480	1480
	900	1300	1450	1450
	Avg 950	Avg 1200	Avg 1447	Avg 1480

Conductor Spacing	50,000 FEET 100% RH WITH CONDENSATION 55°C (131°F) EPOXY SPECIMENS (See MTR 50-60)		50,000 FEET 100% RH WITH CONDENSATION 55°C (131°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
	inches	volts	volts	volts
.010	---	450	---	---
	420	420	300	510
	---	---	250	500
	350	400	320	630
	400	440	340	460
	300	340	320	450
	Avg 377	Avg 410	Avg 306	Avg 510
.015	---	500	400	480
	---	390	340	530
	---	---	400	500
	400	500	280	490
	420	460	370	470
	400	500	350	490
	Avg 407	Avg 470	Avg 340	Avg 493
.022	400	500	450	520
	460	---	320	530
	400	400	410	520
	410	420	430	490
	480	440	410	480
	420	480	420	500
	Avg 428	Avg 448	Avg 407	Avg 507
.025	460	500	470	530
	450	450	340	530
	420	---	440	540
	420	480	720	720
	440	440	480	500
	---	---	420	510
	Avg 438	Avg 467	Avg 478	Avg 555
.032	420	430	470	620
	520	---	330	530
	500	---	480	540
	510	510	500	500
	500	500	470	500
	480	570	480	530
	Avg 488	Avg 502	Avg 455	Avg 537

Conductor Spacing	50,000 FEET 100% RH WITH CONDENSATION 55°C (131°F) EPOXY SPECIMENS (See MTR 50-60)		50,000 FEET 100% RH WITH CONDENSATION 55°C (131°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
inches	volts	volts	volts	volts
.062	590	610	620	700
	610	---	400	580
	700	---	620	700
	660	700	700	760
	720	700	630	700
	680	680	600	660
	Avg 660	Avg 672	Avg 595	Avg 683
.093	800	850	750	900
	820	---	440	580
	820	---	820	820
	800	850	800	900
	880	---	750	880
	600	620	800	890
	Avg 787	Avg 773	Avg 727	Avg 828
.125	800	820	1100	1100
	900	---	600	690
	900	---	900	900
	900	---	960	1050
	800	800	1000	1000
	800	820	850	970
	Avg 850	Avg 813	Avg 902	Avg 952
.187	1000	1030	1050	1050
	1200	---	720	720
	1150	---	1000	1100
	1000	---	1000	1130
	1200	---	1050	1100
	950	960	1000	1050
	Avg 1083	Avg 995	Avg 970	Avg 1025
.250	1050	1050	1450	1450
	600	---	720	720
	1400	---	900	900
	1400	---	900	900
	1300	---	1350	1350
	1300	1300	1250	1300
	Avg 1175	Avg 1175	Avg 1095	Avg 1103

Conductor Spacing	70,000 FEET 90% RH 21°C (70°F) EPOXY SPECIMENS (See MTR 81-59)	
	CORONA DISCHARGE	BREAKDOWN
inches	volts	volts
.010	320	440
	315	440
	320	440
	320	440
	310	430
	Avg 317	Avg 438
.015	320	440
	350	480
	360	460
	350	490
	360	490
	360	490
	Avg 350	Avg 472
.022	360	460
	360	480
	360	440
	Avg 360	Avg 460
.025	370	480
	380	480
	380	470
	350	460
	370	460
	350	470
	Avg 367	Avg 470
.032	380	460
	350	460
	400	460
	380	470
	390	490
	380	480
	Avg 380	Avg 470

Conductor Spacing	70,000 FEET 100% RH WITH CONDENSATION 71°C (160°F) EPOXY SPECIMENS (See MTR 50-60)		70,000 FEET 100% RH WITH CONDENSATION 71°C (160°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
inches	volts	volts	volts	volts
.010	300	350	300	530
	320	330	320	520
	340	400	300	540
	320	400	320	530
	340	- -	300	540
	300	320	300	530
	Avg 320	Avg 360	Avg 307	Avg 532
.015	320	- -	300	540
	340	480	320	530
	360	500	310	520
	320	480	310	530
	380	480	320	530
	380	390	300	500
	Avg 350	Avg 466	Avg 310	Avg 525
.022	340	- -	280	520
	400	420	320	520
	340	460	320	520
	360	480	310	530
	380	460	320	520
	380	440	320	520
	Avg 367	Avg 452	Avg 312	Avg 522
.025	360	- -	320	520
	420	480	320	520
	350	480	280	520
	380	480	330	520
	380	480	340	520
	380	440	330	520
	Avg 378	Avg 472	Avg 320	Avg 520
.032	240	- -	340	510
	440	460	340	530
	400	490	310	520
	410	480	360	530
	400	480	370	540
	400	440	340	530
	Avg 382	Avg 470	Avg 343	Avg 527

Conductor Spacing	70,000 FEET 100% RH WITH CONDENSATION 71°C (160°F) EPOXY SPECIMENS (See MTR 50-60)		70,000 FEET 100% RH WITH CONDENSATION 71°C (160°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
	inches	volts	volts	volts
.062	400	- -	400	550
	460	520	450	550
	480	520	470	560
	500	540	470	570
	540	- -	460	570
	440	- -	460	560
	Avg 470	Avg 527	Avg 452	Avg 560
.093	520	- -	520	580
	480	520	560	580
	500	580	520	590
	600	640	540	590
	600	620	520	600
	480	520	540	600
	Avg 530	Avg 576	Avg 533	Avg 590
.125	- -	- -	590	620
	560	- -	680	680
	560	640	670	670
	600	- -	560	620
	660	700	600	640
	560	600	600	630
	Avg 588	Avg 647	Avg 617	Avg 643
.187	- -	- -	570	600
	600	- -	760	820
	580	600	670	670
	650	700	690	740
	750	800	710	750
	600	- -	680	740
	Avg 636	Avg 700	Avg 680	Avg 720
.250	- -	- -	810	810
	800	- -	900	900
	600	- -	970	970
	900	- -	800	800
	1000	- -	890	900
	700	- -	810	850
	Avg 800		Avg 863	Avg 872



Conductor Spacing	80,000 FEET DRY 150°C (302°F) EPOXY SPECIMENS (See MTR 93-61)		80,000 FEET 90% RH 21°C (70°F) EPOXY SPECIMENS (See MTR 81-59)	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
inches	volts	volts	volts	volts
.010	300	not measured	330	350
	300		330	340
	300		320	350
	300		320	320
	325		310	340
			310	320
	Avg 305		Avg 320	Avg 337
.015	300	not measured	320	400
	325		330	420
	300		340	420
	325		340	350
	325		340	350
			350	350
	Avg 315		Avg 337	Avg 382
.022	300	not measured	315	400
	325		340	370
	325		330	390
	300		360	410
	350		360	390
	Avg 320		Avg 341	Avg 392
.025	325	not measured	370	410
	350		360	390
	325		360	380
	350		360	400
	350		370	390
			360	380
	Avg 340		Avg 363	Avg 392
.032	350	not measured	360	400
	350		380	380
	350		390	390
	375		360	390
	375		350	400
			380	380
	Avg 360		Avg 370	Avg 390

Conductor Spacing	80,000 FEET DRY 150°C (302°F) EPOXY SPECIMENS (See MTR 93-61)	
	CORONA DISCHARGE	BREAKDOWN
inches	volts	volts
.062	425 425 450 425 450 Avg 435	not measured
.093	525 475 500 475 480 Avg 491	not measured
.125	500 525 500 500 550 Avg 515	not measured
.187	650 625 650 700 700 Avg 665	not measured
.250	800 700 700 800 800 Avg 760	not measured

Conductor Spacing	80,000 FEET 91% RH 125°C (257°F) EPOXY SPECIMENS (See MTR 50-60)		80,000 FEET 91% RH 125°C (257°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
	volts	volts	volts	volts
inches				
.010	290	490	300	550
	300	340	300	550
	230	340	340	570
	300	380	300	560
	290	370	290	570
	270	270	310	550
	Avg 280	Avg 365	Avg 307	Avg 558
.015	300	380	290	550
	300	360	310	530
	280	380	300	580
	300	420	300	580
	280	590	300	540
	270	360	310	560
	Avg 288	Avg 415	Avg 302	Avg 557
.022	300	450	290	540
	300	430	300	530
	300	400	330	590
	340	500	320	580
	270	570	290	550
	270	510	320	660
	Avg 297	Avg 477	Avg 308	Avg 575
.025	280	490	290	540
	300	510	340	530
	290	520	310	590
	350	500	- -	760
	270	440	330	650
	280	390	- -	- -
	Avg 295	Avg 475	Avg 317	Avg 614
.032	280	450	290	550
	280	490	330	520
	280	490	330	570
	350	510	330	540
	290	460	300	550
	280	450	310	550
	Avg 293	Avg 475	Avg 315	Avg 547

Conductor Spacing	80,000 FEET 91% RH 125°C (257°F) EPOXY SPECIMENS (See MTR 50-60)		80,000 FEET 91% RH 125°C (257°F) PHENOLIC SPECIMENS (See MTR 50-60)	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
	volts	volts	volts	volts
inches	volts	volts	volts	volts
.062	400	470	330	540
	370	490	380	550
	360	500	400	530
	320	480	400	550
	300	490	350	550
	300	500	400	560
	Avg 342	Avg 488	Avg 377	Avg 547
.093	440	480	350	570
	370	510	380	570
	350	510	430	550
	340	500	420	560
	310	500	430	570
	320	510	470	580
	Avg 355	Avg 502	Avg 413	Avg 567
.125	380	520	440	600
	420	550	490	600
	390	550	510	570
	340	500	490	590
	320	520	540	590
	360	570	500	610
	Avg 368	Avg 535	Avg 495	Avg 593
.187	400	550	480	640
	480	580	560	650
	400	580	510	610
	360	560	510	610
	330	580	570	660
	500	590	600	670
	Avg 412	Avg 573	Avg 538	Avg 640
.250	500	590	570	660
	500	610	650	650
	400	520	650	700
	400	560	620	630
	400	570	650	710
	580	660	650	700
	Avg 463	Avg 585	Avg 632	Avg 675

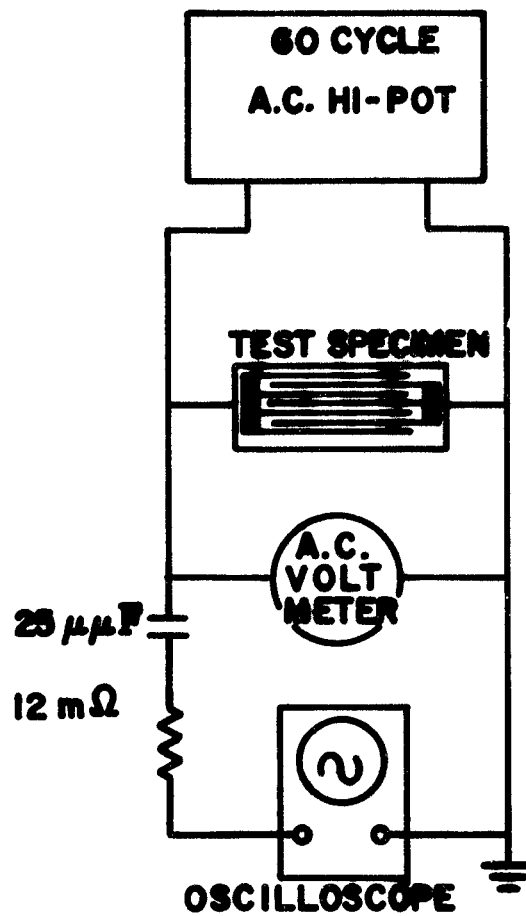
Conductor Spacing	80,000 FEET 100% RH WITH CONDENSATION 95°C (203°F) EPOXY SPECIMENS (See MTR 50-60)		80,000 FEET 100% RH WITH CONDENSATION 95°C (203°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
inches	volts	volts	volts	volts
.010	300	400	310	600
	300	410	290	760
	290	560	300	560
	300	520	300	580
	280	360	300	550
	170	---	320	560
	Avg 273	Avg 450	Avg 303	Avg 602
.015	300	400	310	570
	290	480	270	560
	300	530	280	560
	290	440	250	520
	290	340	290	550
	300	490	330	570
	Avg 295	Avg 447	Avg 288	Avg 555
.022	320	540	340	520
	300	480	300	560
	290	490	310	530
	290	480	330	510
	290	500	370	600
	320	490	320	650
	Avg 302	Avg 497	Avg 328	Avg 562
.025	200	---	310	510
	290	490	290	530
	280	470	300	530
	300	480	430	560
	300	470	330	650
	---	---	320	610
	Avg 274	Avg 477	Avg 330	Avg 565
.032	340	480	350	520
	300	460	320	540
	290	490	340	530
	300	490	350	530
	300	460	340	570
	320	500	---	---
	Avg 303	Avg 480	Avg 340	Avg 538

Conductor Spacing	80,000 FEET 100% RH WITH CONDENSATION 95°C (203°F) EPOXY SPECIMENS (See MTR 50-60)		80,000 FEET 100% RH WITH CONDENSATION 95°C (203°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
	inches	volts	volts	volts
.062	380	500	390	530
	320	460	330	540
	300	490	380	540
	380	490	430	520
	340	490	400	550
	460	530	400	560
	Avg 363	Avg 493	Avg 388	Avg 540
.093	540	---	450	560
	350	480	400	580
	400	490	420	570
	380	510	500	600
	400	500	470	590
	510	560	480	570
	Avg 430	Avg 508	Avg 453	Avg 578
.125	520	580	540	580
	400	510	560	590
	400	560	510	610
	400	530	550	590
	450	540	550	600
	530	580	540	610
	Avg 450	Avg 550	Avg 542	Avg 597
.187	500	550	590	630
	420	540	500	640
	460	570	600	680
	480	560	580	710
	440	570	600	670
	550	660	560	640
	Avg 475	Avg 575	Avg 572	Avg 662
.250	400	450	600	650
	540	560	760	820
	600	680	630	690
	520	590	600	700
	500	580	780	780
	650	1000	680	720
	Avg 535	Avg 643	Avg 675	Avg 727

Conductor Spacing	100,000 FEET 91% RH 125°C (257°F) EPOXY SPECIMENS (See NFR 50-60)		100,000 FEET 91% RH 125°C (257°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
	inches	volts	volts	volts
.010	270	590	---	570
	300	590	280	660
	210	740	300	640
	210	580	320	700
	230	630	320	690
	280	1000	290	650
	Avg 250	Avg 688	Avg 302	Avg 652
.015	380	700	300	600
	300	600	---	740
	---	---	280	580
	320	580	300	630
	230	520	310	900
	230	520	300	800
	Avg 292	Avg 584	Avg 298	Avg 708
.022	270	440	290	630
	230	530	290	600
	220	470	280	570
	250	480	300	650
	230	500	300	670
	210	510	280	610
	Avg 235	Avg 488	Avg 290	Avg 622
.025	230	470	290	570
	200	520	270	530
	220	450	270	540
	230	460	300	580
	240	480	300	830
	210	490	310	710
	Avg 222	Avg 478	Avg 290	Avg 627
.032	240	430	280	580
	200	500	300	620
	230	460	270	570
	220	450	300	580
	230	480	300	930
	210	500	---	---
	Avg 222	Avg 470	Avg 290	Avg 656

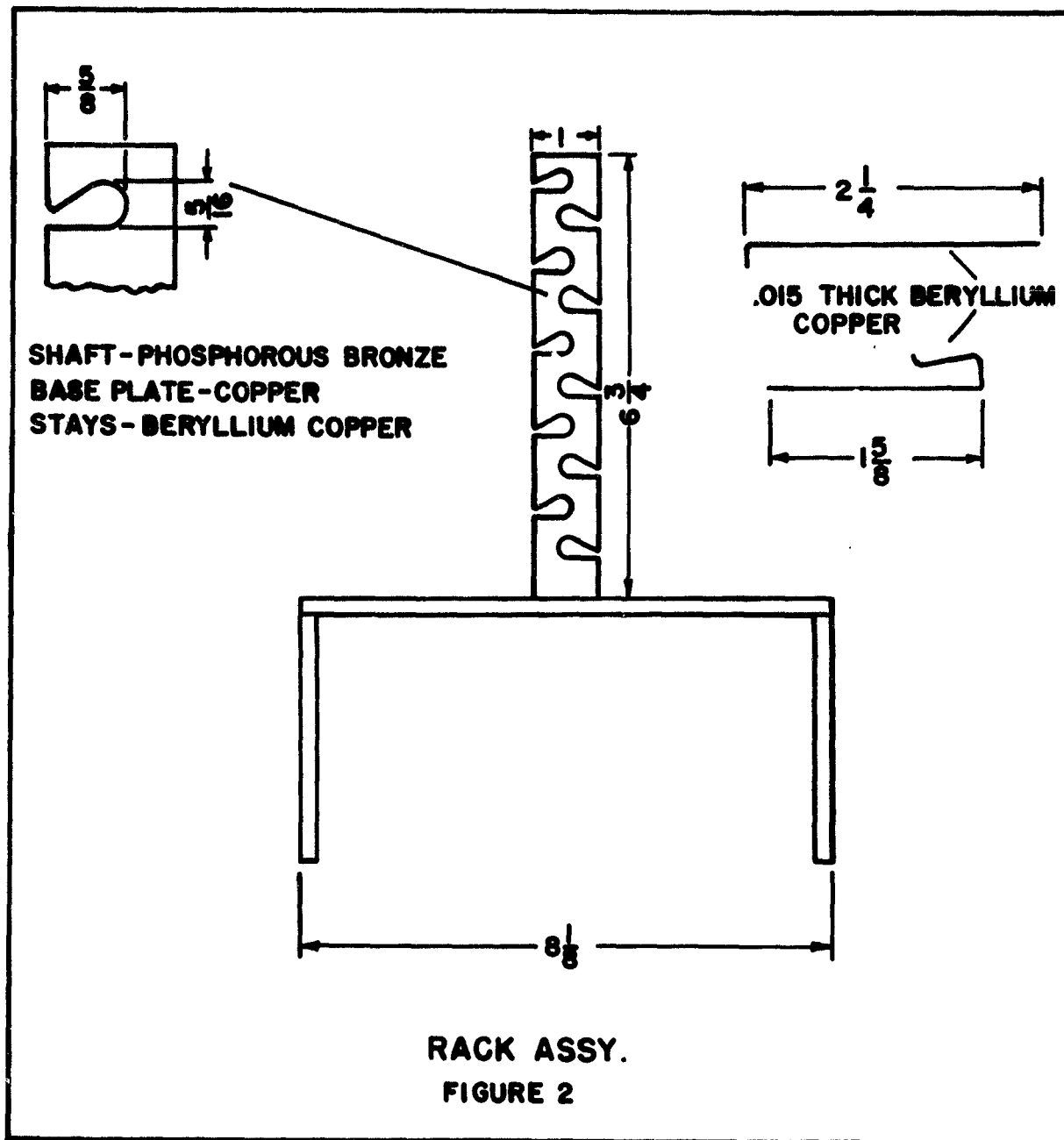
Conductor Spacing	100,000 FEET 91% RH 125°C (257°F) EPOXY SPECIMENS (See MTR 50-60)		100,000 FEET 91% RH 125°C (257°F) PHENOLIC SPECIMENS	
	CORONA DISCHARGE	BREAKDOWN	CORONA DISCHARGE	BREAKDOWN
	inches	volts	volts	volts
.062	290	460	320	530
	290	520	340	490
	300	440	280	500
	270	450	330	520
	230	460	330	520
	280	490	360	520
	Avg 277	Avg 470	Avg 327	Avg 513
.093	230	440	320	540
	310	490	360	510
	260	480	300	520
	300	470	360	500
	250	480	370	510
	240	490	400	520
	Avg 265	Avg 475	Avg 352	Avg 517
.125	260	460	360	530
	370	490	410	520
	370	490	350	530
	320	490	400	510
	360	500	390	520
	330	510	410	530
	Avg 335	Avg 490	Avg 387	Avg 523
.187	400	520	430	540
	350	500	420	560
	390	500	450	550
	360	530	410	550
	400	530	450	550
	340	530	490	580
	Avg 373	Avg 518	Avg 442	Avg 555
.250	500	560	420	550
	320	510	500	580
	410	520	470	580
	440	570	460	580
	450	560	400	580
	410	550	580	590
	Avg 422	Avg 545	Avg 472	Avg 577





SCHEMATIC - SKETCH

FIGURE 1



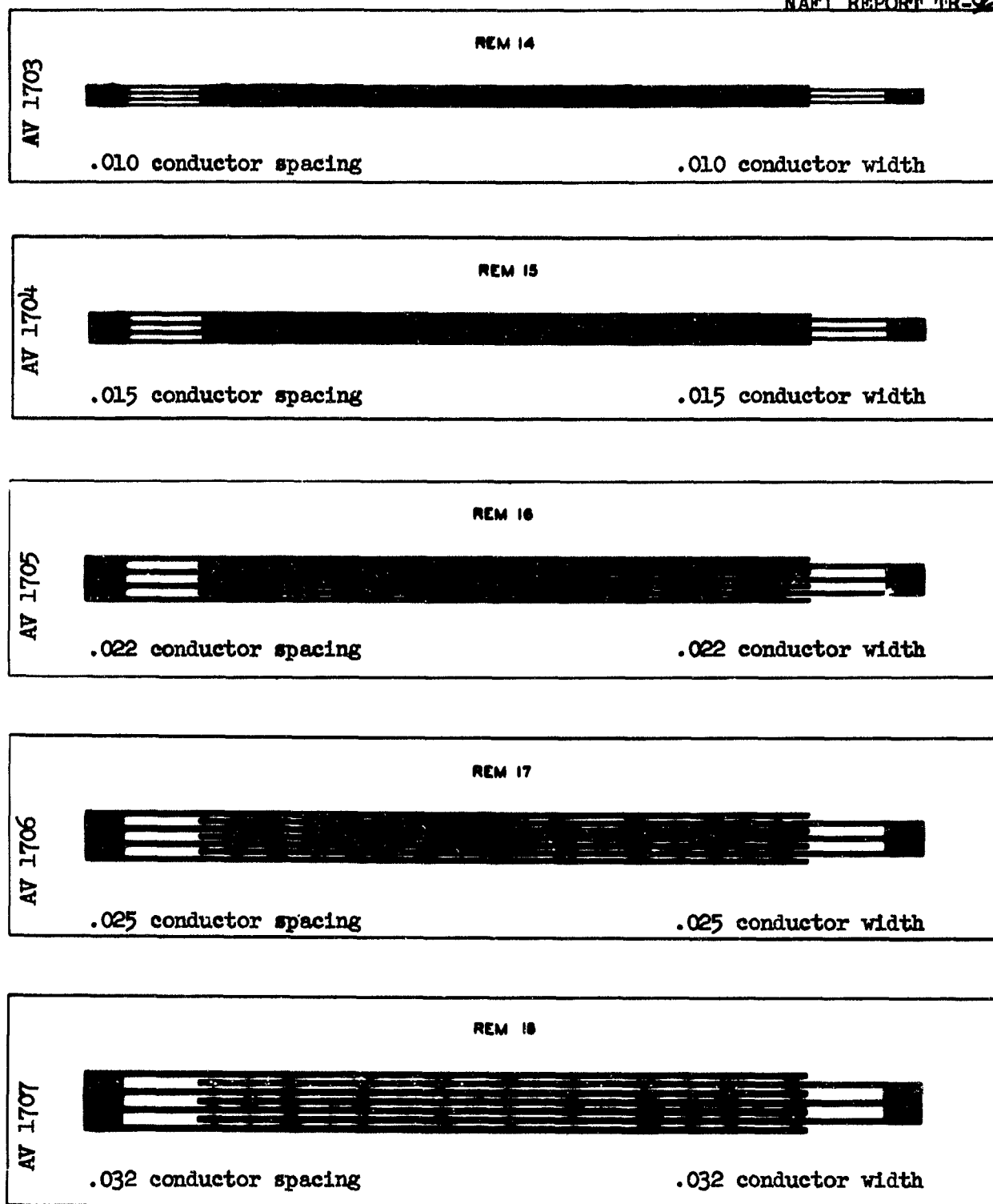
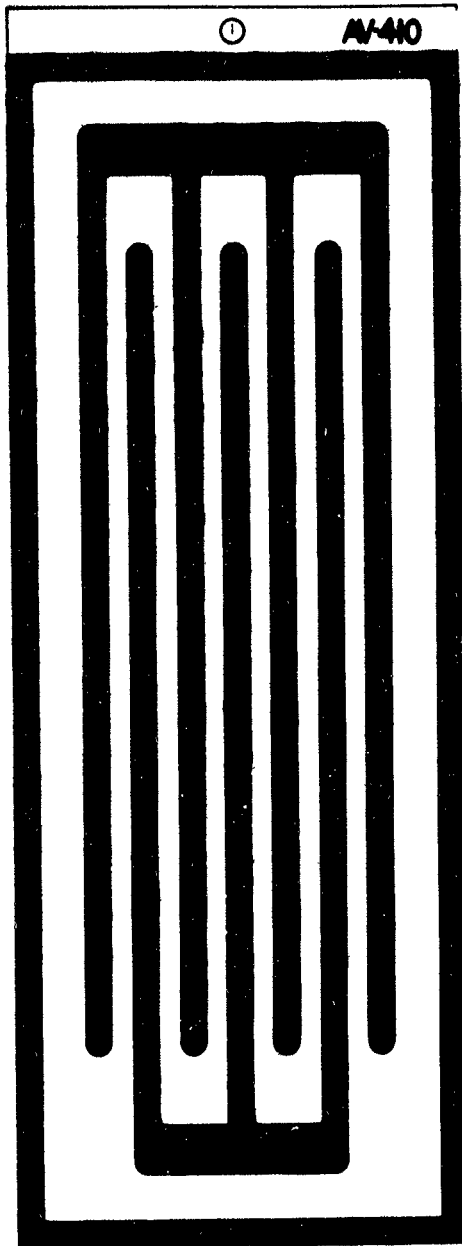
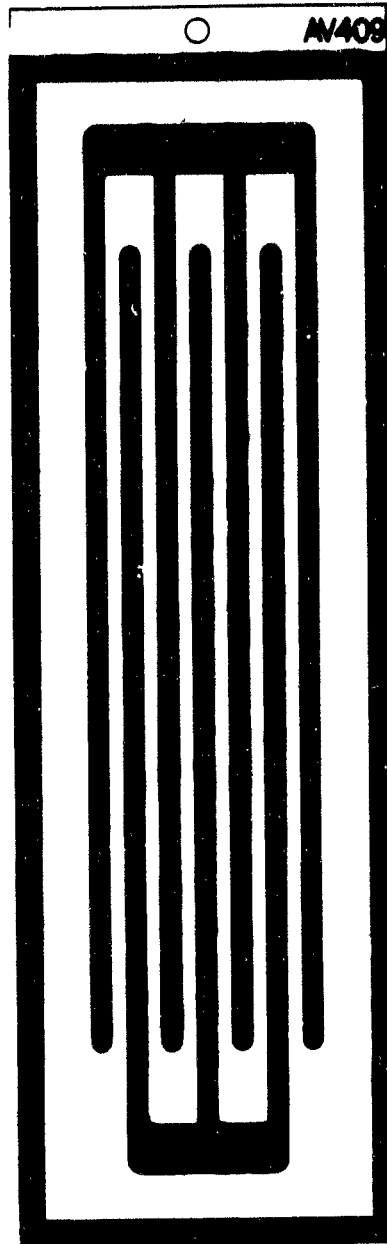


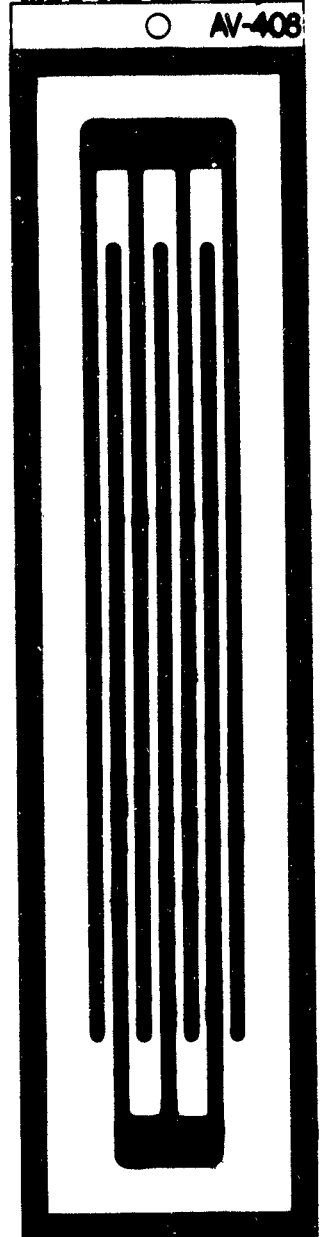
Figure 3.



.1250 conductor spacing  
.1250 conductor width



.0937 conductor spacing  
.0937 conductor width

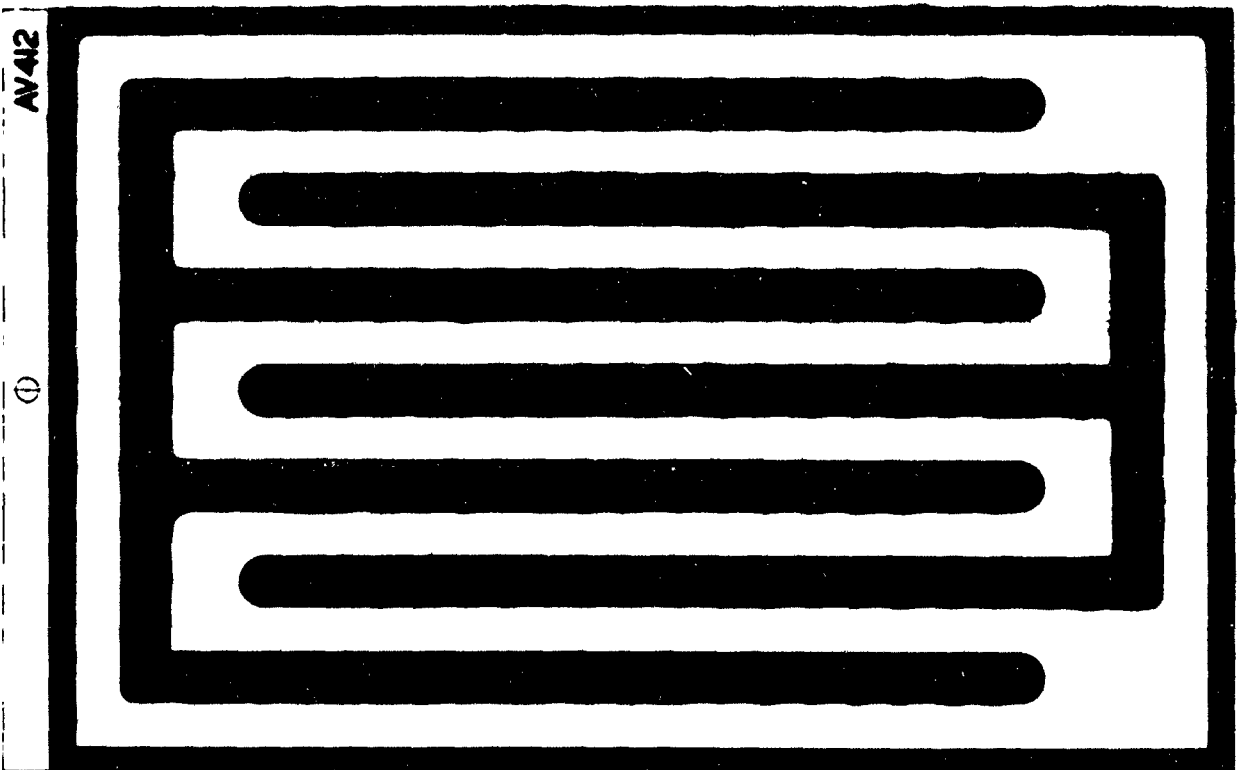


.0625 conductor spacing  
.0625 conductor width

Figure 4.

.1875 conductor spacing

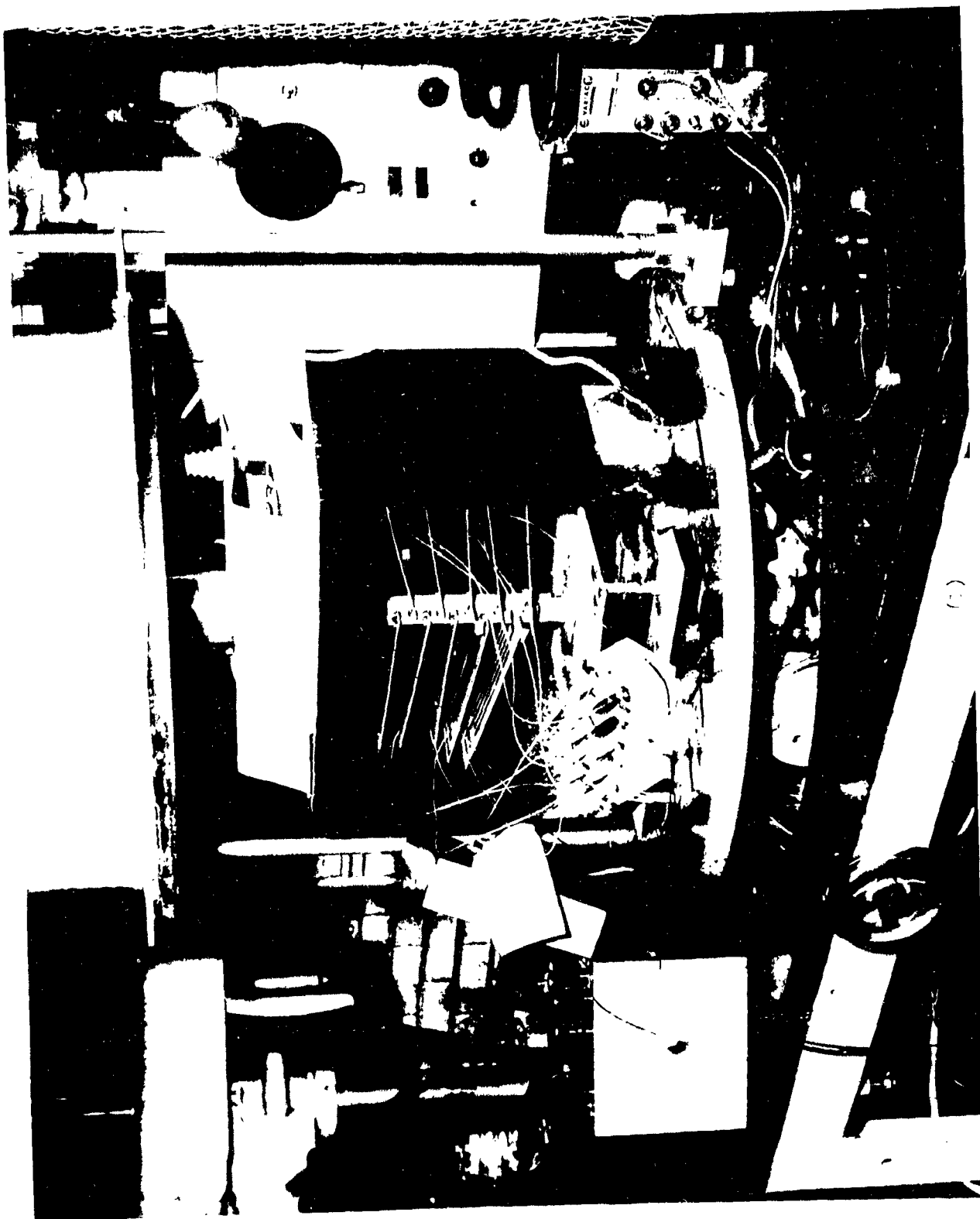
.1875 conductor width

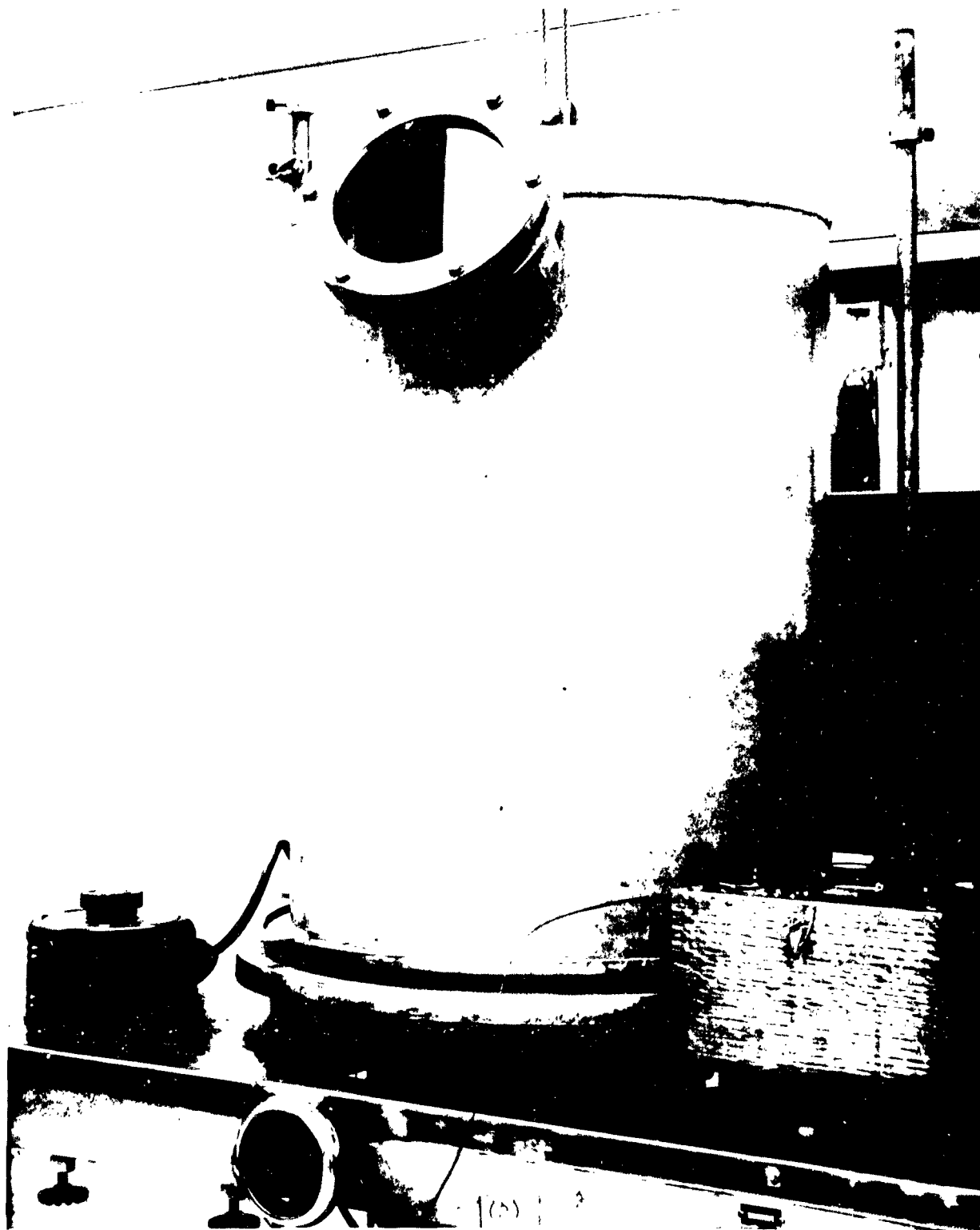


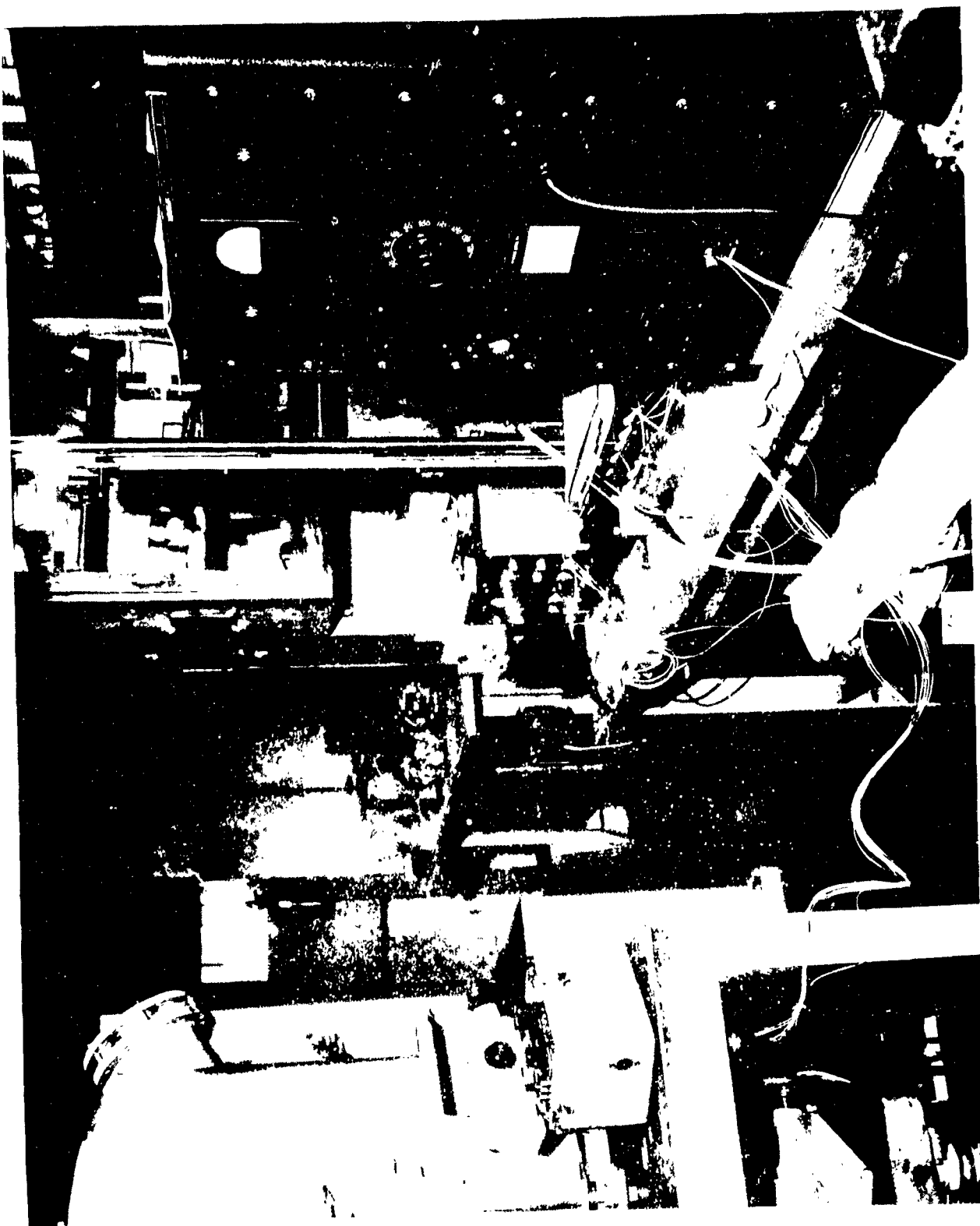
.250 conductor spacing

.250 conductor width

Figure 5.









REFERENCES

- (a) NAFI Materials Test Report No. 14-57
- (b) NAFI Materials Test Report No. 81-59
- (c) NAFI Materials Test Report No. 50-60
- (d) NAFI Materials Test Report No. 93-61
- (e) MIL-STD-275
- (f) MIL-STD-446
- (g) MIL-E-5400
- (h) BuWeps Drawing No. AV 1633
- (i) BuWeps Drawing No. AV 2806
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